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Agricultural Memorandum No 203

Frost in Thetford Chase - 1967 Experiments

by
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Introduction

Agricultural Memoranda Nos. 108, 144 and 170 described experiments from 1964 to 1966 on minimum temperatures in spring in Thetford Chase. The investigation was undertaken because of losses due to frosting of Corsican pine in late spring in 1962 and 1963.

Experiments and sites

The experiments in 1967 were conducted on a much more geographically restricted scale, with considerable modification in layout. Some of the points earlier investigated were considered as established, and this year a few different approaches were tried. No further meteorological readings were taken at the 1966 sites of Mundford, Lynford, Mundford under-cover, West Tofts, Santon Nursery, Santon Ride and High Lodge, and limited use was made of Kings, with only weekly readings. Two important innovations were the introduction of run-of-wind anemometers at several sites, and maximum/minimum soil thermometers. The anemometers were read daily at 0900 GMT with the rest of the observations, and were exposed as discussed below. The soil maximum/minimum thermometers were also read daily at 0900 GMT. These were introduced in the light of very interesting spot values at 0900 GMT in 1966 at a depth of 8 inches. Unfortunately, the maximum/minimum thermometers were available for a depth of 4 inches, and not 8 inches, but the results which emerged were striking; they have been discussed in Agricultural Memorandum No. 197.

Harling Nursery (Site 8). A 4-ft shielded thermometer, and a vertical array were installed as last year. Additionally, a 4-in max/min soil thermometer and two anemometers at 6 ft (the standard agromet exposure) and 1 ft were used from April to June.

Harling (Sites 9-11). The three sites were maintained for 4-ft and 6-in thermometers as before, and additionally a vertical array was mounted at the grassed site 10. Anemometers at 6 ft and 1 ft were put in at sites 9 (the litter site) and 10, and max/min soil thermometers at all sites, with two at site 10. Site 11 was the small (square chain) area of bare soil.

Harling Ride (Site 16). This was an open ride, about 90 ft broad between trees and running north/south, with a 1° upslope towards the south. The grass was cropped fairly close, and the area could be regarded as clear (within the limitation of 40/45 ft trees growing on either side). 4-ft and 6-in thermometers were installed, and so were two anemometers.

Harling under-cover (Site 1). This was nearby, with the instruments consisting of 4-ft and 6-in thermometers, a vertical array, two anemometers and a soil thermometer installed under about 75% of canopy provided by trees around 40 ft high.

Kings. 4-ft and 6-in thermometers were maintained here, and anemometers were put in at 6 ft, 8 in (in the open) and 8 in (in a furrow). Analysis of results could be only partial, as readings were taken weekly and so were not a satisfactory basis for comparison between the daily readings from other stations.

/Analysis

Analysis

The soil temperatures have been analysed in Agricultural Memorandum No.197, and will not be referred to again here. Otherwise a very similar analysis has been made for 1967 as for example described in Agricultural Memorandum No.170, with consideration of the three vertical arrays, an analysis of the 6-in thermometer readings, a similar one of the 4-ft readings (together with a comparison of years in 10 during which frost can be expected). Additionally some analysis was also made on the records obtained from the daily anemometer readings.

Comparison of 4-ft thermometer readings with Mildenhall

Fig.1 shows the difference between the various stations at which 4-ft cocoa-tin mounted thermometers were maintained as a difference between the stations and Mildenhall; temperatures for the various stations were corrected according to the formula used last year (Agricultural Memorandum No.170) cf

$$T_s = T_m + 1.0 + 0.2\ (T_n - T_g).$$

T_s = corrected value of minimum temperature; T_m = cocoa-tin reading; T_n = screen reading at Mildenhall; and T_g = grass minimum reading at Mildenhall.

Four stations are the same as those used last year; no.8 at Harling Nursery and Nos.9-11 at Harling. The two fresh sites are the under-cover Site 1 and the wide ride Site 16. The only week in which a fairly regular pattern is broken is week 8, 20/26 May, which was unsettled with a greater flow of wind than during any other week in the experiment; minimum temperatures were slightly higher than in neighbouring weeks.

The gain in under-cover temperature readings at night is obvious at the under-cover Site 1, and only in week 8, the windy week, was it not less cold than almost everywhere else. The ride, Site 16, was intermediate between Harling Nursery and the other Harling sites, and like the under-cover site it benefited much less in the windy week 8.

Table 1 shows a comparison of the difference of the 13 week average minimum temperatures at Mildenhall with those of the other stations for 1965, 1966 and 1967.

Table 1

Difference of temperatures at the various sites and Mildenhall, 1965, 1966 and 1967 (including 1967 sites only)

Year	Site No. 1	8	9	10	11	16
		(deg F)				
1965		-1.3	-2.8	-3.0	-2.3	
1966		-1.8	-3.4	-3.4	-3.0	
1967	-1.0	-1.4	-3.4	-2.9	-3.0	-2.0

Very little change is shown in Harling Nursery in 3 years and not much at the other Harling sites, but a curious feature is that for the first time, the temperature at 4 ft above bare soil at Site 11 was not quite as warm as over grass (Site 10). The difference is very slight, and could well be due to the increased scrubby vegetation which has grown on the bare plot in the last 2 to 3 years. Differences are however low enough almost to be an experimental error - certainly the 2.9°F and 3.0°F of 1967 for Sites 10 and 11 are negligible differences. The gain in freedom from frost within a ride

/(Site 16)

(Site 16) compared with open vegetated land can be seen - and the under-cover Site 1 is distinctly warmer at night than at 4 ft over bare soil at Harling Nursery.

Frequency of years in ten with frosts after specific dates

The risk of a frost on or after a particular week was again assessed, exactly as last year, and results were fairly similar. Table 2 considers 1967 in isolation.

Table 2

(a) Weeks during and after which a risk of temperatures below 32°F can be expected at Thetford.

Week Commencing	Site No. 1	8	9	10	11	16
1st April	10	10	10	10	10	10
29th April	9	10	10	10	10	10
27th May	1	2	9	9	9	4
24th June	0	0	5	3	3	+

(b) Weeks during and after which a risk of temperatures below 28°F are expected at Thetford.

Week Commencing	Site No. 1	8	9	10	11	16
1st April	10	9	10	10	10	10
29th April	7	7	10	10	10	9
27th May	+	1	4	4	4	1
24th June	0	0	1	1	1	0

The figures for Sites 8 to 11 are similar to last year's, but are not identical, and the truth probably lies in rather higher figures, and Table 3 gives the suggested full table for temperatures below 32°F and below 28°F.

Table 3

(a) Dates after which a risk of temperatures below 32°F are expected at Thetford (weighted 1965-1967 data)

Week Commencing	Site No. 1	8	9	10	11	16
1st April	10	10	10	10	10	10
8th April	10	10	10	10	10	10
15th April	10	10	10	10	10	10
22nd April	10	10	10	10	10	10
29th April	9	10	10	10	10	10
6th May	9	10	10	10	10	10
13th May	8	9	10	10	10	9
20th May	6	8	10	9	9	8
27th May	2	5	9	8	8	5
3rd June	1	2	8	7	6	2
10th June	+	1	6	5	4	1
17th June	0	0	4	3	2	+
24th June	0	0	2	1	1	0

/(b)

(b) Dates after which a risk of temperatures under 28°F are expected at Thetford (weighted 1965-1967 data)

Week Commencing	Site No. 1	8	9	10	11	16
1st April	10	10	10	10	10	10
8th April	9	10	10	10	10	10
15th April	8	10	10	10	10	9
22nd April	7	9	10	10	10	9
29th April	7	9	10	10	10	9
6th May	3	7	10	9	9	6
13th May	2	6	9	9	8	4
20th May	1	3	7	7	6	2
27th May	+	2	5	4	3	1
3rd June	0	1	3	2	2	+
10th June	0	+	2	1	1	+
17th June	0	+	1	1	1	+
24th June	0	0	1	+	+	0

The sites are:

1 Under-cover 9 Harling litter 11 Harling (bare earth)
8 Harling Nursery 10 Harling grass 16 Ride

This means that in late May, there was still about an even chance of a temperature as low as 28°F at Harling over litter, and much the same over grass, but the risk is considerably lower within a ride or over a large expanse of bare soil, and is very low indeed under a forest canopy. There is a slight improvement at Harling Nursery compared with the Harlings in 1967 - mainly because of the slightly smaller difference in temperature between Mildenhall and Harling Nursery. Possibly the Nursery has been kept clearer this year. Harling Ride is slightly less favourable than the narrower Santon Ride of last year, but the Harling under-cover site is slightly less frosty than the somewhat less leafy High Lodge and Mundford sites of last year.

Temperatures at 6 inches

In previous years a comparison has been made between temperature readings (uncorrected) at the various sites and Kings. This year a similar comparison could not be made, because weekly readings only were taken at Kings, so Fig.2 shows the actual average weekly minimum temperatures at the various sites. The figure brings out immediately the coldness of weeks 4 and 11 and to a lesser extent 5. Almost unbrokenly, the temperature over bare soil at Harling Nursery is less cold at 6 in than anywhere else, and the two Harling sites over litter and over grass are much the coldest. The under-cover site is only a little cooler than Harling Nursery, and the ride is a little cooler than the small bare patch. The only week in which Harling Nursery was distinctly colder than the under-cover site was the cold week 4 - so in a sudden burst of cold weather, the forest retains its heat.

The lack of change in the pattern over the last 3 years is shown by Table 4, in which differences for the whole period between the various stations and Harling Nursery are shown.

Table 4

Differences of temperatures (average April/June) at 6 in for the various sites minus Harling Nursery

Year	Site No 1	9	10	11	16	
1965		-4.0	-4.4	-2.1		deg F
1966		-4.9	-4.4	-2.1		deg F
1967	-0.4	-5.3	-4.7	-1.8	-2.7	deg F

/Interestingly,

Interestingly, the grass and the litter sites at Harling Nursery are colder, if anything, and the small bare site less so this year. Again however these differences are small and of doubtful significance.

Vertical array

Vertical arrays exactly similar to last year's were assembled. Three arrays instead of two were employed: Harling Nursery as before, Harling grass replacing Mundford as a grassed, clearing site, and a third at the Harling under-cover site. Fig. 3 shows the weekly averages at the various heights for the three locations; the similarity between 1966 Mundford and Harling Nursery (Fig. 3, Agricultural Memorandum No.170) and 1967 Harling grass and Harling Nursery is striking. In fact, the average differences 2/72 in over the 13 weeks for Mundford in 1965 and 1966 and for Harling grass in 1967 were 3.9°F, 4.5°F and 4.6°F; the means of the three coldest nights each week were 5.6°F, 6.5°F and 6.4°F, and the largest inversions in the three seasons were 9.0°F, 11.3°F and 9.6°F. The vertical structure over these rather enclosed grassed sites is thus very similar.

To make a comparison between 1966 and 1967 at Harling Nursery is not easy, as there are strong doubts about the 72-in thermometer in 1967. It was checked on return to Bracknell and appeared in error by about 0.3°F - just the difference between the average reading at 48 in and at 72 in. In 1966 the average minimum temperatures were virtually isothermal from 12 in to 72 in, and apart from the 72-in reading of 40.3°F, the 1967 profile is also practically isothermal at 40.6°F. Because of this uncertainty, comparison of the 72/2 in temperature differences between 1966 and 1967 cannot be made. The array mounted within the canopy brought out several interesting features. An average of 1.4°F existed between 2 in and 72 in, and although the temperatures at 2 in and 6 in were below those above bare soil in the open, the temperature at 24 in (and from there upwards) was higher within the wood than over the open bare ground. The slope of the curve suggested a difference of about 1°F from the 6 ft level probably to the base of the canopy; immediately above this of course the temperature would be much lower, probably of the order of that near the vegetation covered ground surrounding the wood. It will be borne in mind that temperature changes within the canopy will be far less than those outside, and day maximum temperatures particularly in sunny weather will be far lower under cover than out in the open.

All three curves on Fig. 3 show that week 4, 22nd-28th April was outstandingly the cold week in the season, but week 11 (10th-16th June) was also very cold comparatively - and colder over grass than the 13 week average. This naturally occurred during the period of cold northerly winds, and even near the south coast some overnight frost was reported on the mornings of 12th and 13th June. The coldest June night was actually at the end of week 10 on the 9th June, with frosts at 4 ft at the Harlings, and almost at Harling Nursery as well.

Table 5

Frequency of occasions each week April-June 1967 with temperatures below 32°F and below 28°F at Harling sites

Harling Nursery

Week	in :	Below 32°F 2	6	12	24	48	72	Below 28°F 2	6	12	24	48	72
1		2	2	2	2	2	2	2	2	2	2	2	2
2		2	2	2	2	2	2	.	.	.	.	.	1
3		1	1	1	1	1	1	.	.	1	1	1	1
4		4	4	4	4	4	4	2	2	2	2	2	3
5		2	2	2	2	2	2	1	1	2	2	2	2
6		.	.	.	.	.	.	.	.	.	.	.	.
7		.	.	.	.	.	.	.	.	.	.	.	.
8		.	.	.	.	.	.	.	.	.	.	.	.
9		.	.	.	.	.	.	.	.	.	.	.	.
10		1	1	1	1	1	1	.	.	.	.	.	.
11		.	.	.	.	.	.	.	.	.	.	.	.
12		.	.	.	.	.	.	.	.	.	.	.	.
13		.	.	.	.	.	.	.	.	.	.	.	.
1967		12	12	12	12	12	12	5	5	7	7	7	9
1966		5	7	5	5	5	5	1	1	1	1	1	1

Table 5 (contd)

Harling under cover

Week	in :	Below 32°F 2	6	12	24	48	72	Below 28°F 2	6	12	24	48	72
1		2	2	2	2	2	2	1	1	1	1	1	1
2		2	2	2	2	2	2	.	.	.	.	.	.
3		1	1	1	1	1	1	.	.	.	.	.	.
4		4	4	4	4	4	4	2	1	1	1	1	1
5		2	2	2	2	2	2	1	1	1	1	1	.
6		.	.	.	.	.	.	.	.	.	.	.	.
7		.	.	.	.	.	.	.	.	.	.	.	.
8		.	.	.	.	.	.	.	.	.	.	.	.
9		.	.	.	.	.	.	.	.	.	.	.	.
10		.	.	.	.	.	.	.	.	.	.	.	.
11		.	.	.	.	.	.	.	.	.	.	.	.
12		.	.	.	.	.	.	.	.	.	.	.	.
13		.	.	.	.	.	.	.	.	.	.	.	.
1967		11	11	11	11	11	11	4	3	3	3	3	2

Harling over grass

Week	in :	Below 32°F 2	6	12	24	48	72	Below 28°F 2	6	12	24	48	72
1		2	2	2	2	2	2	1	1	1	1	1	1
2		2	2	2	2	2	2	2	2	2	2	2	2
3		3	3	3	3	2	1	2	2	2	1	1	1
4		5	5	5	4	4	4	4	4	4	4	3	3
5		4	4	4	4	3	3	4	4	3	3	2	2
6		2	2	1	1	1	.	1	1	.	.	.	.
7		3	1	.	.	.	.	.	.	.	.	.	.
8		1	.	.	.	.	.	.	.	.	.	.	.
9		3	3	3	2	1	.	1	1	.	.	.	.
10		2	2	1	1	1	1	1	1	1	1	1	1
11		4	4	4	3	1	.	4	4	2	1	.	.
12		1	1	1	1	.	.	1	1	1	.	.	.
13		.	.	.	.	.	.	.	.	.	.	.	.
1967		32	29	26	23	17	13	21	21	16	13	10	10
1966		25	26	19	13	10	7	11	10	9	5	3	3
1965		23	19	17	16	13	13	14	11	9	8	4	2

Table 5 gives the frequencies of (uncorrected) temperatures of below 32°F and below 28°F at the three stations. In general, of course, the screen temperature is higher (by perhaps 2°F?) than the temperature an unprotected thermometer shows - but the trees are also unprotected, after all! In analysis of earlier years, it had been stated that both 1965 and 1966 had been frost-free years. 1967 was however considerably more frosty, as the comparative figures for Harling Nursery (1966 and 1967) and Mundford/Harling grass show. Judging by Mildenhall, 1967 was about average, the number of frosts in April and May being 5 and 0 respectively, compared with the long term averages of 4.5 and 1.3.

The freedom from frost at Harling Nursery compared with an open site is striking, especially near the ground. Again, there is very little change with height - a slight increase indeed away from any warming caused by the ground; the figure of nine at 72 in is probably one (if not two) in error because of the under-reading of the thermometer. Figures are much higher than last year, especially at the 28°F level of coldness.

/The

The difference between cocoa-tin temperature readings at 4 ft at Mundford and Harling grass in 1965 and 1966 was of the order of 1°F (with Mundford warmer) but it is reasonable to consider the comparison of the two in the table valid, at least for the distribution in the vertical, and again the much lower frequency of temperatures below 32°F and below 28°F at 72, 48 and 24 in compared with 2 in and 6 in is obvious.

The Harling under-cover figures are most interesting. The frequency of temperatures below 32°F is identical with that of Harling Nursery, except for week 10. In this week, 9th June was exceptionally cold, and at Harling Nursery the temperature was as low as 30.8°F at 12 in; at Harling over grass the temperature fell to 21.2°F at 2 in and 6 in. Within the forest however, the temperature at 6 in of 32.7°F was the coldest, and it was 33.2°F at 2 in and 33.5°F at 72 in. The measure of insulation provided by canopy against a sudden dramatically cold night is obvious. A curious point which happened to emerge from this analysis was that the frequency of temperatures below 32°F did not vary with height; in view of the shape of the vertical soundings of Fig.3 this must have been fortuitous, and in fact frequency of temperatures below 28°F are higher near the ground, as might be expected. In 1967 at least, frequencies of temperatures below 32°F were very similar at Harling Nursery and under the canopy, but below 28°F the canopy protection proved considerably greater. Interestingly, if 26°F had been taken as the criterion, the figures of the Nursery site for heights 2 in to 72 in would have been 4, 3, 3, 3, 4, 5, and under the canopy 3, 3, 1, 1, 1, 1; a 24°F level would give 1, 2, 2, 2, 2, 2, for the Nursery and 1, 1, 1, 1, 0, 0, under canopy, and the only reading under 22°F was an isolated 21.9°F at Harling Nursery at 2 in on the 1st April.

Finally, Fig.4 shows in the same way as in Agricultrual Memorandum No.170 last year the weekly extreme gradients of temperature from 72 to 2 in for the coldest night, the average of the 3 coldest nights, and of all nights for each week. The Harling grass curves are similar to last year's for Mundford, though with less difference between the coldest and the 3 coldest nights, and with several occasions (notably week 6) where the difference was much less with the coldest night; this was possibly an occasion when mist or fog prevented a really low temperature. Apart from very early in the season, the three stations are well separated, with almost no difference at Harling under-cover greater than 3°F, and with most under 2°F. Values for Harling Nursery are negative, because of the 72-in thermometer.

Wind flow in Thetford Chase

For the first time in the experiments, anemometers were mounted, 11 in all. Four of these had the "standard" agromet exposure at a height of 2 metres above ground: Kings, Harling Nursery, Harling litter and Harling grass, and for interest comparison is made with the agromet station of Santon Downham, 10 miles to the west-northwest. Five were exposed at a height more significant to young plants at 1 ft, at the same three sites at Harling and also at the Harling under-cover sites and in the nearby ride. Additionally two were placed at a height of 8 in at Kings, one in the open and the second in a furrow; the Kings anemometers were read weekly, but all the others were read daily at 0900 GMT.

6-ft anemometers. As Fig.5 shows, the windy site clearly was the open Kings, with a through flow of 14,761 miles during the 3 months; this corresponded to an overall average speed of 6.8 mph. The greatest weekly flow was that of 1,643 miles during 20th/26th May (9.8 mph). Harling litter, a little surprisingly, was the second windiest site with distinctly greater flow of air than at Harling Nursery (12,134 miles compared with 11,005 miles). The Harling litter site is however distinctly more open than Harling grass, so the low wind at the latter is quite acceptable; the flow here of 9,850 miles contains an element of estimate, as the anemometer was not installed until 13th April. The enclosed nature of Santon Downham agromet station is brought out by the air flow over the 13 weeks being as low as 8,950 miles.

/1-ft anemometers

1-ft anemometers. Very interesting is the substantially greater air movement in Harling Nursery compared with the other sites. Air flow was of the order of 50% more than in the Harling compartment, where the air movement over the litter site was distinctly greater than over grass. Well brought out is the support of stagnancy (which we have) arraigned against Harling in the past, but it is emphasised as at low level, with rather stronger air flow at 6 ft over litter than at Harling Nursery. From the general appearance of these sites, the Harling grass site would have been expected to suffer more from stagnancy than the litter site.

Perhaps predictably, with its channelling of air flow (and therefore lessening of any cross wind component) the ride wind was lighter again, and very predictably the under-cover air flow was much lower, amounting to only about 10% of that at Harling Nursery.

It is not intended to dwell on the Kings instruments, read only once weekly at a different height from the other anemometers. The results have however been plotted on Fig.5 to afford a comparison, and it is seen from this that the flow in the open at 8 in at Kings (4,317 miles) is mostly close to the Mundford over grass at Harling, especially in April and May. The 8-in anemometer in a furrow is obviously very protected, and the flow of this level in furrowed ground was even less (at 704 miles) than within the forest canopy at a height of 1 ft, where the total flow was 846 miles (a mean wind speed of 0.4 mph).

In general, it probably can be concluded that over an open surface (exemplified by Harling Nursery) the wind at 1 ft is around two-thirds that at 6 ft, but that in a more stagnant terrain covered by grass or other low vegetation, the factor is about half. Over similar vegetation at Kings, the factor between air flow at 8 in and 6 ft was about one-third, but air flow in furrows is relatively very light indeed. Finally, the records did not suggest any unserviceability of the anemometers, as the pattern of divergence between the various sites was very similar from one week to the next.

Conclusions

The following conclusions are mostly based on the 1967 experiments, but for completeness some background mention is made as to what was found in earlier work.

1. At a height of 4 ft, there was more freedom from frost within a forest canopy than outside (and appreciably more with denser canopy) but a narrow ride (less than say 20 yards wide) gives almost as much freedom from frost as 70% canopy. Bare soil affords better protection than a wide ride (say 30 yards or more across). Least favourable are rather enclosed vegetation covered sites.

2. The findings of 1. above are reflected in years of freedom from frost. Thus at the start of June the risk of temperatures of below 28°F ranged from 5 year in 10 risk in places like Harling to a 2 year in 10 risk at Harling Nursery or a broad ride and 1 year in 10 in a narrow ride or under light canopy. The risk is low under denser canopy.

3. At a height of 6 in above the ground, differences in temperature in various exposures are considerably greater than at 4 ft. On the whole, a large expanse of bare soil affords maximum protection against cold temperatures, but dense canopy can give greater freedom from low temperatures in a sudden cold spell. Narrow rides are probably the next best frost preventor, followed by a small bare earth area and a wide ride.

4. The vertical arrays show that freedom from low temperatures was maintained all the way between 2 in and 72 in over bare soil, with very big gains

/over

over natural vegetation, especially near the ground. Under cover, the temperature in the lowest few inches was lower than over bare soil, but above 2 ft the temperature in the canopy was higher.

5. Wind flow at 6 ft is controlled mostly by the openness of the terrain, but at 1 ft the type of earth cover is important. Greatest wind flow was over bare soil, and least within the canopy and at almost the level of a furrow top.

6. Soil temperatures in late spring and early summer show a change of pattern. In early/mid spring, minimum temperatures are lower under bare soil than elsewhere, but in late spring and in early summer, night temperatures are less cold under bare soil than under vegetation or within a forest canopy. Average maximum day temperatures are always higher in spring and summer under bare soil, and can average in June over 10°F higher in maximum between bare soil and under canopy.

7. Changes of exposure have proved in the past to show up; for example more grass at Kings two or three years ago showed up as an increased frost risk.

Acknowledgements

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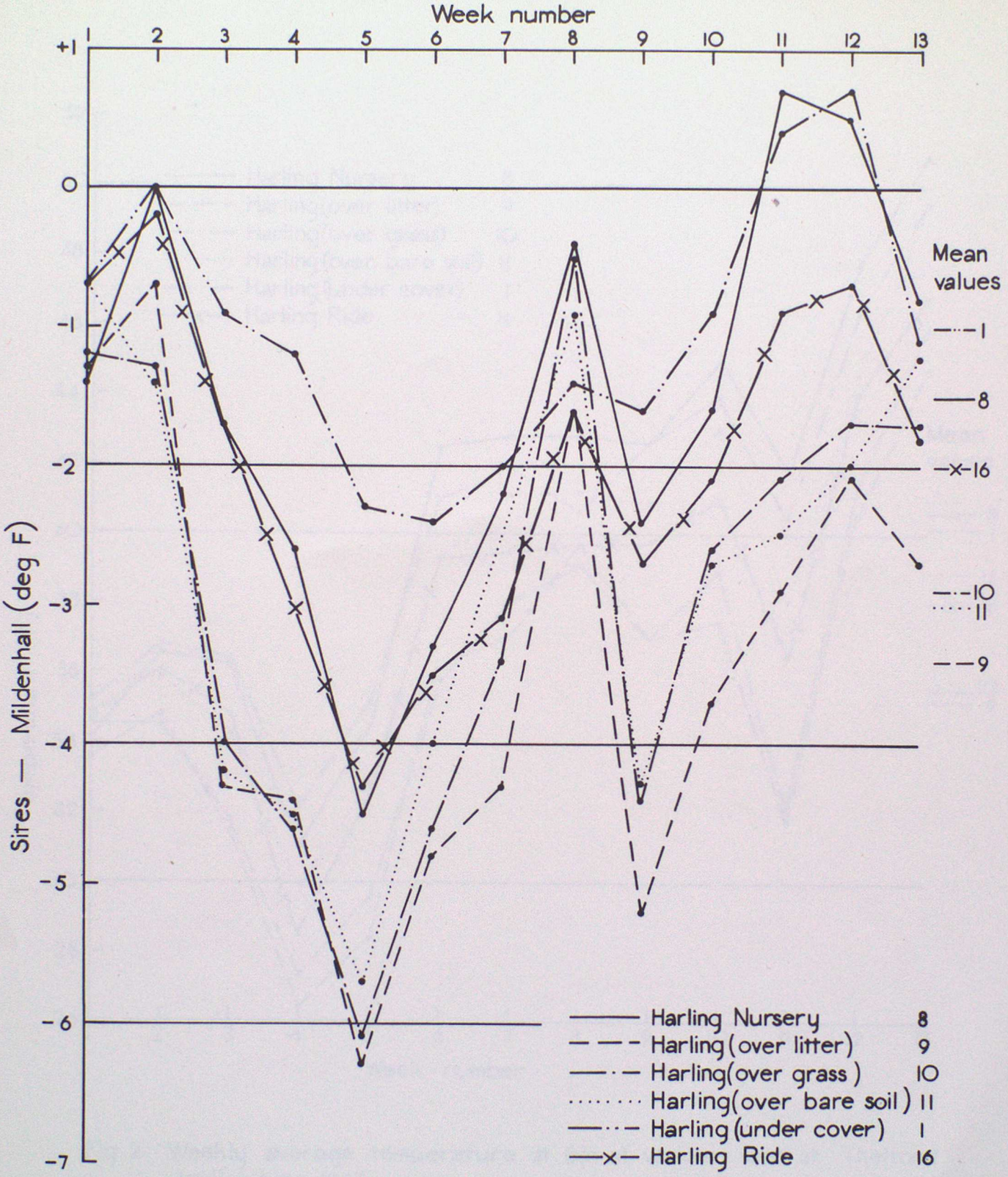


Fig 1 Weekly average differences in minimum temperatures between the various Thetford (Harling area) sites and Mildenhall at standard height of 4ft. April—June 1967

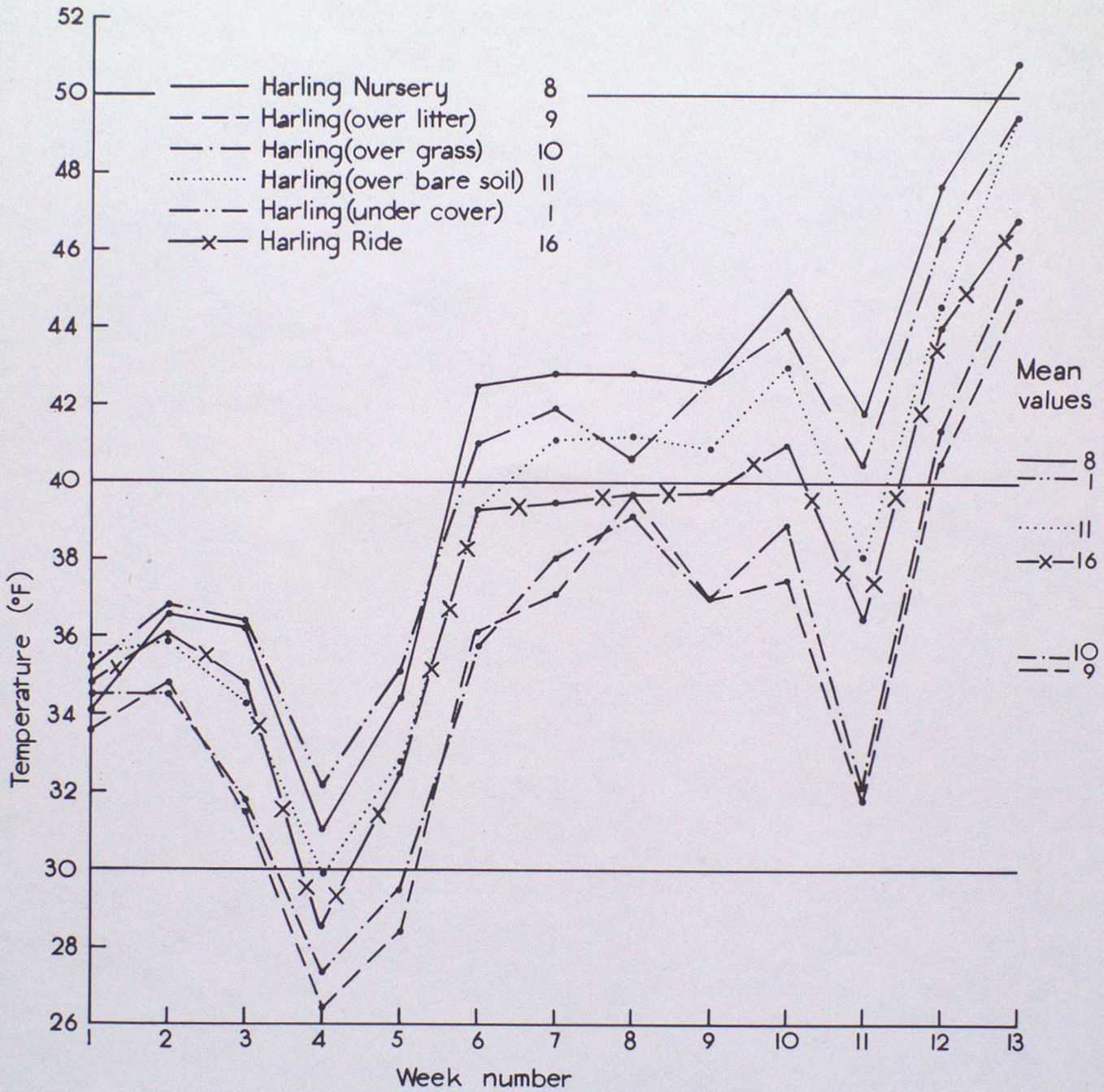


Fig 2 Weekly average temperature at 6in at various sites at Thetford April – June 1967

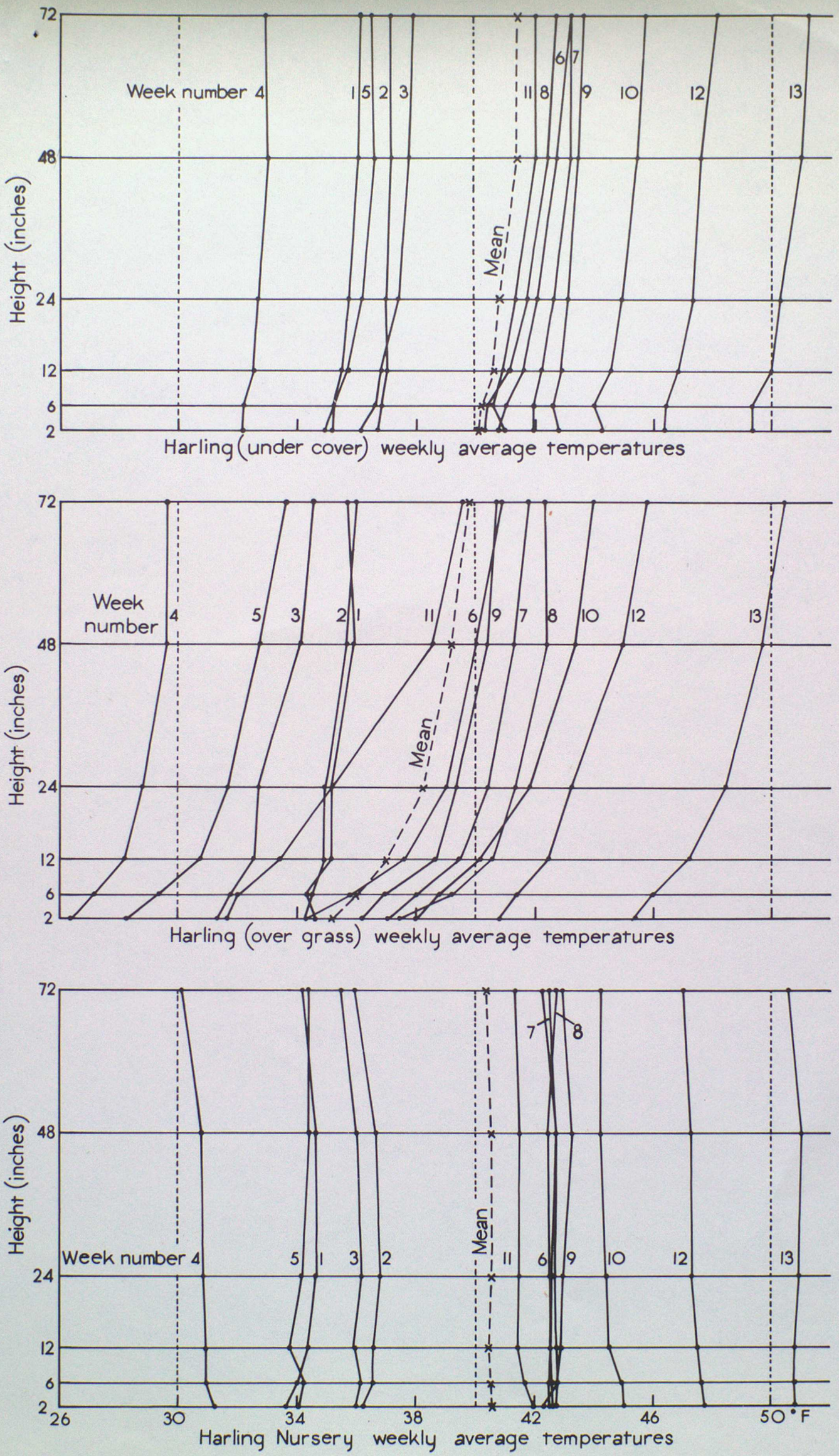


Fig 3 Vertical temperature soundings at Harling during April–June 1967

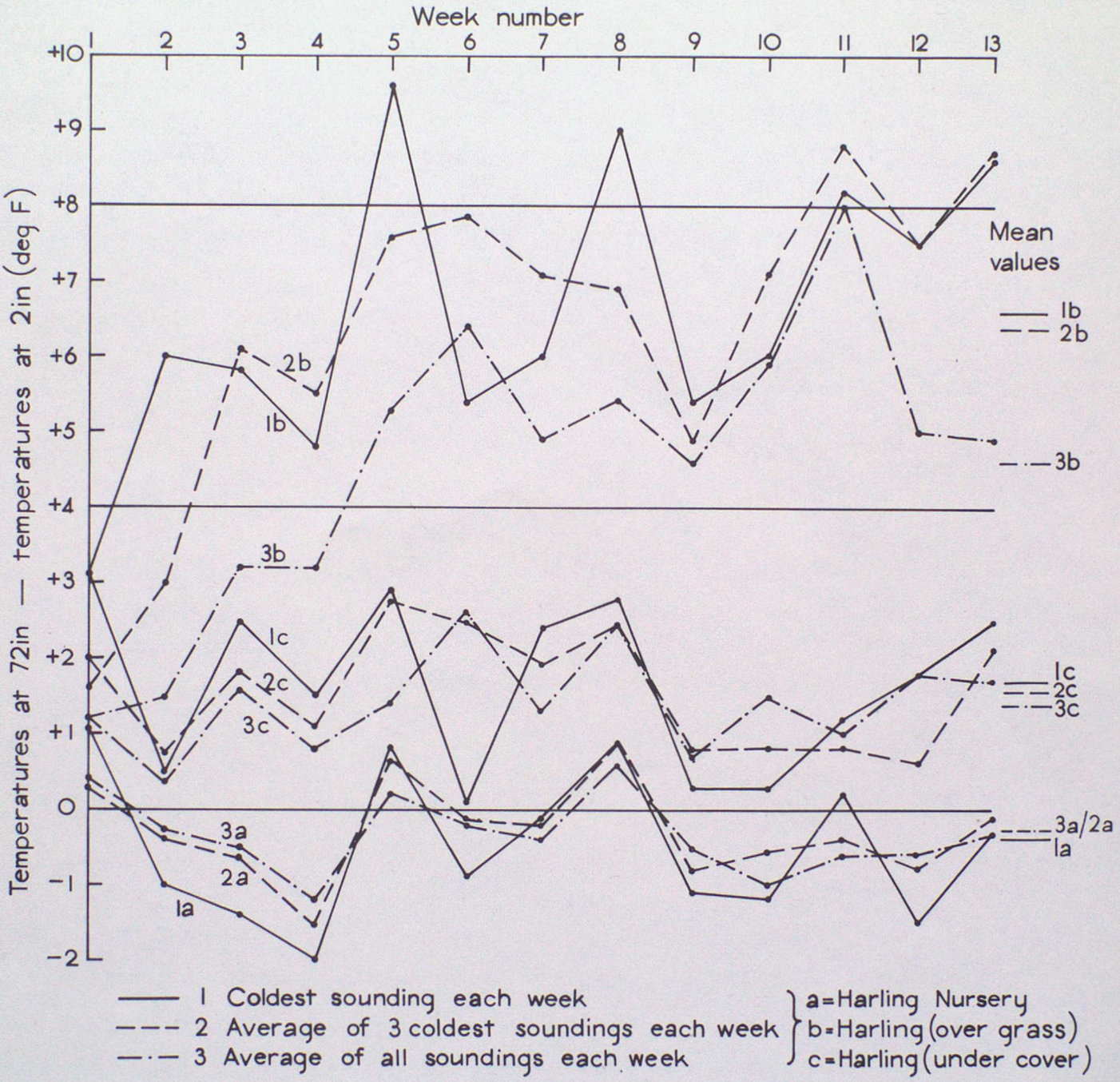
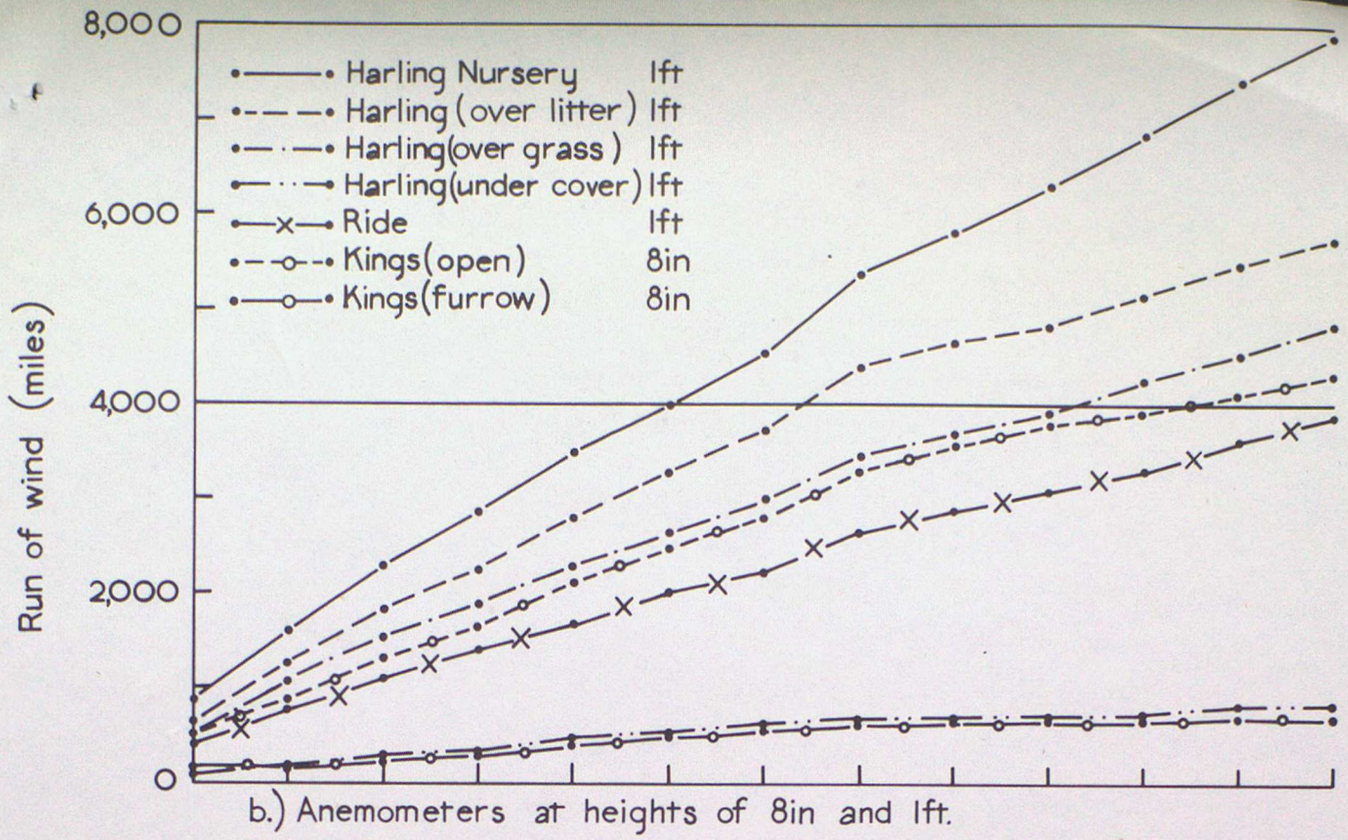
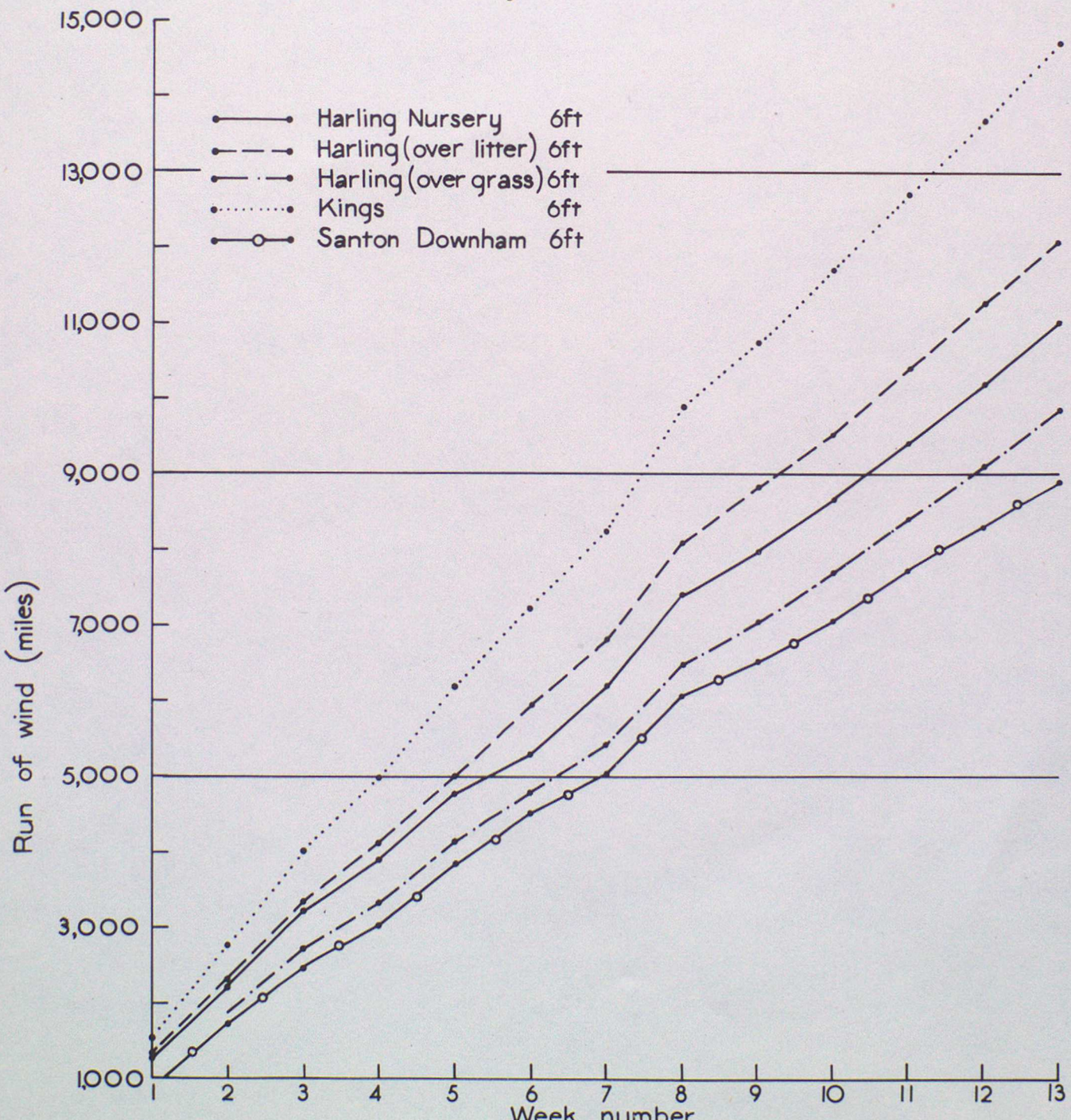


Fig 4 Temperature difference between 72 and 2 inches at Harling sites during April – June 1967.



b.) Anemometers at heights of 8in and 1ft.



a.) Anemometers at height of 6ft.

Fig 5 Weekly totals of run of wind at various sites at Thetford
April – June 1967